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Smith

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(54) **CURRENT SENSING SYSTEM AND METHOD**

(75) Inventor: **Harold Arthur Smith**, Tyrone, GA (US)

(73) Assignee: **Panasonic Automotive Systems of America, division of Panasonic Corporation of North America**, Peachtree City, GA (US)

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H03F 3/04 (2006.01)

(52) **U.S. Cl.** **330/298**; 381/55

(58) **Field of Classification Search** .... 381/86, 381/77, 389, 302, 56, 365, 55; 341/139; 327/103, 524, 530, 538; 363/73; 323/304, 323/311, 282, 312, 234, 315, 265, 235; 330/253, 330/256, 202 P, 298; 455/117

See application file for complete search history.

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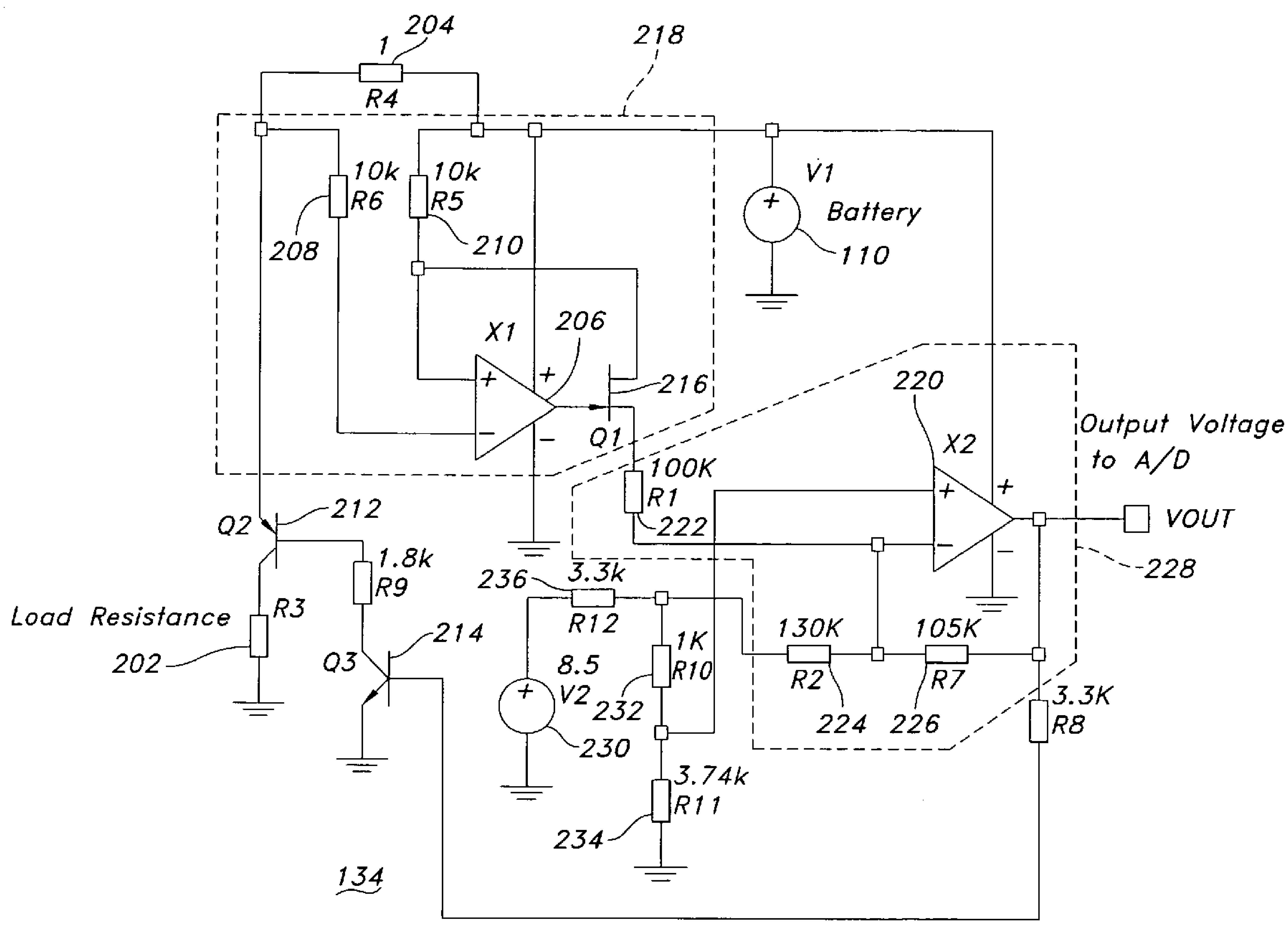
Primary Examiner — Davetta W Goins
Assistant Examiner — Lun-See Lao
(74) *Attorney, Agent, or Firm* — Laurence S. Roach

(57) **ABSTRACT**

There is provided a current sense circuit (**134**). An exemplary current sense circuit (**134**) comprises a voltage-to-current converter circuit (**218**) that is adapted to receive a voltage that is proportional to a load current drawn from a battery (**110**) by a load (**202**) and to produce a current proportional to the load current, and a current-to-voltage converter circuit (**228**) that is adapted to receive the current proportional to the load current and to produce a voltage proportional to the load current based on a regulated voltage source (**230**).

16 Claims, 4 Drawing Sheets



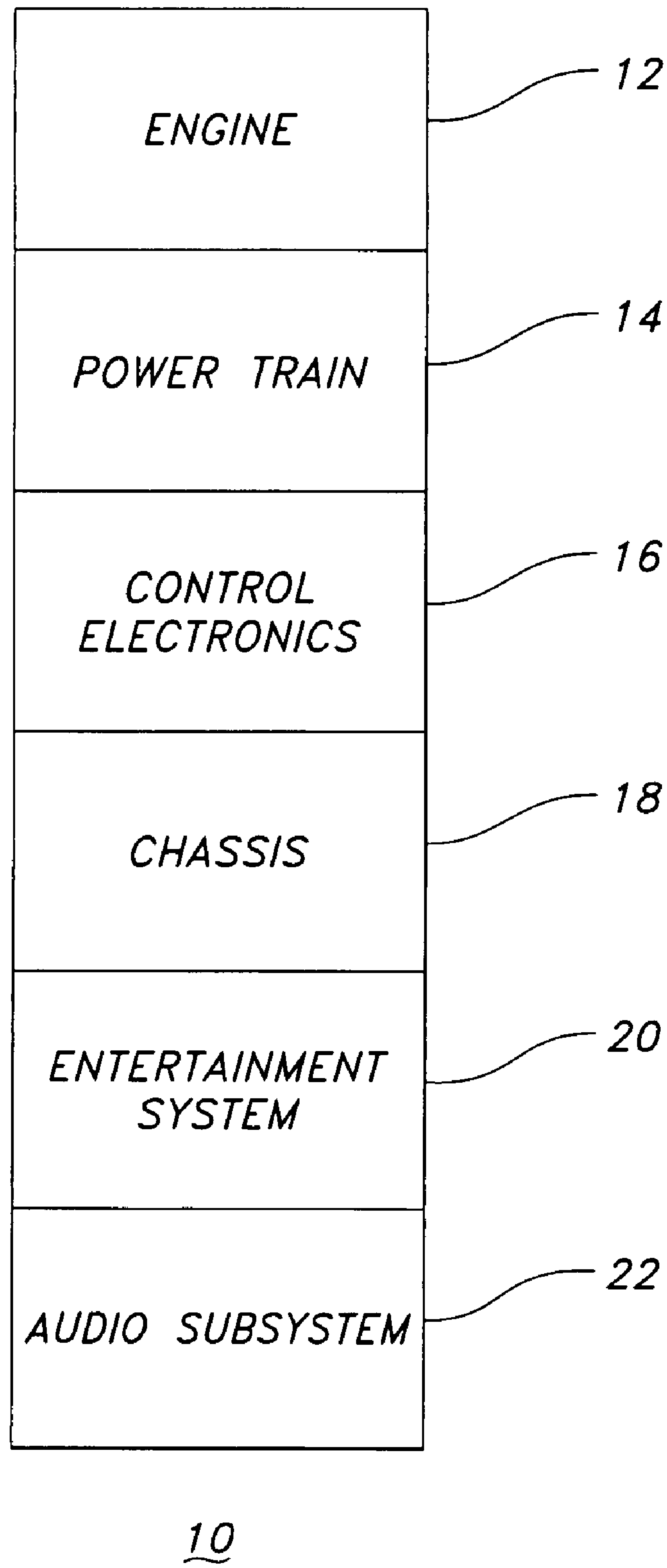

ENGINE
12
POWER TRAIN
14
CONTROL ELECTRONICS
16
CHASSIS
18
ENTERTAINMENT SYSTEM
20
AUDIO SUBSYSTEM
22
10

FIG. 1

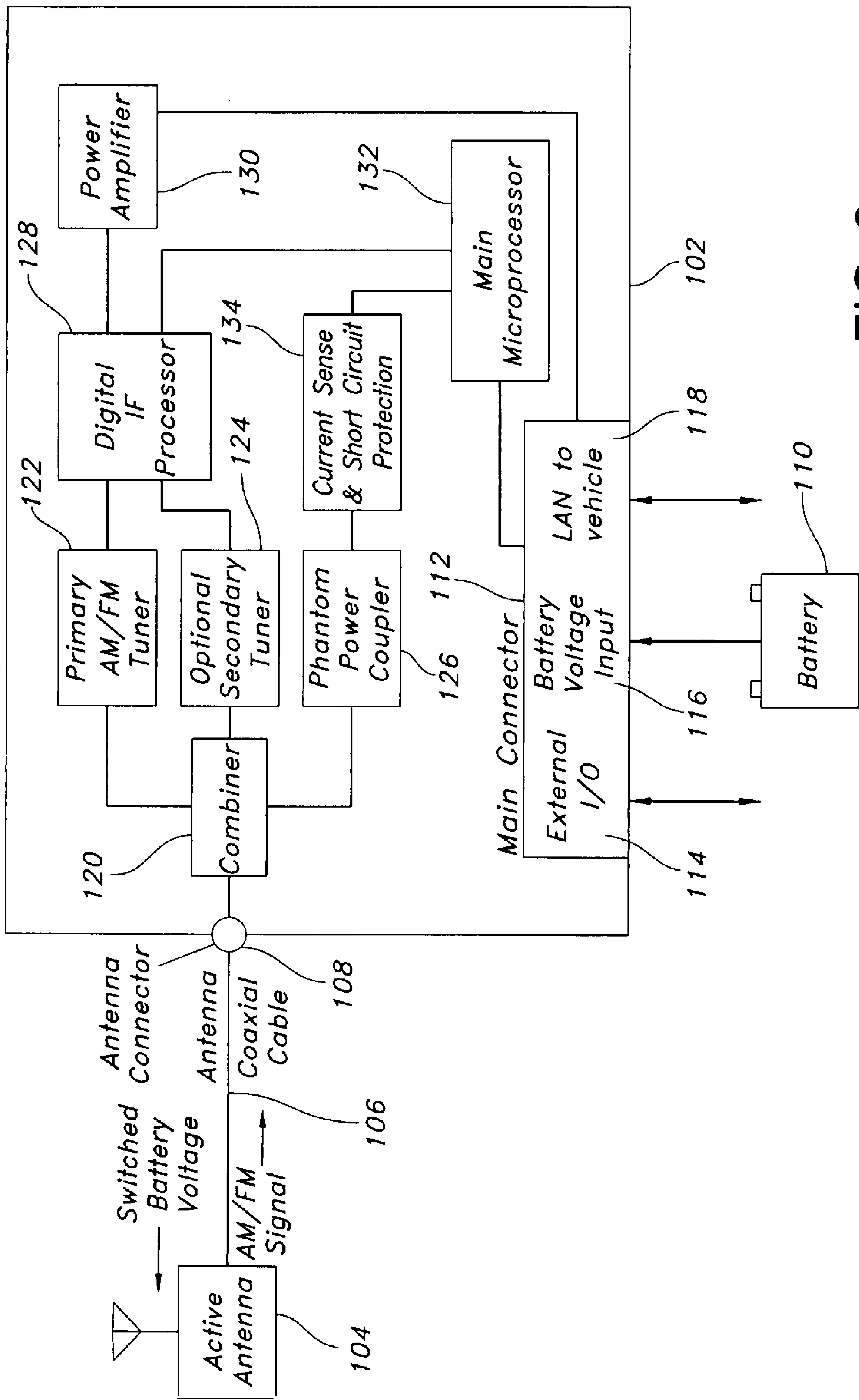

Power Amplifier
130
132
Main Microprocessor
128
Digital IF Processor
134
Current Sense & Short Circuit Protection
102
122
124
118
Primary AM/FM Tuner
Optional Secondary Tuner
Phantom Power Coupler
112
LAN to vehicle
110
126
Main Connector
Battery Voltage Input
Battery
116
Combiner
External I/O
120
114
Antenna Connector
Antenna
Coaxial Cable
108
Switched Battery Voltage
106
AM/FM Signal
Active Antenna
104

FIG. 2

22

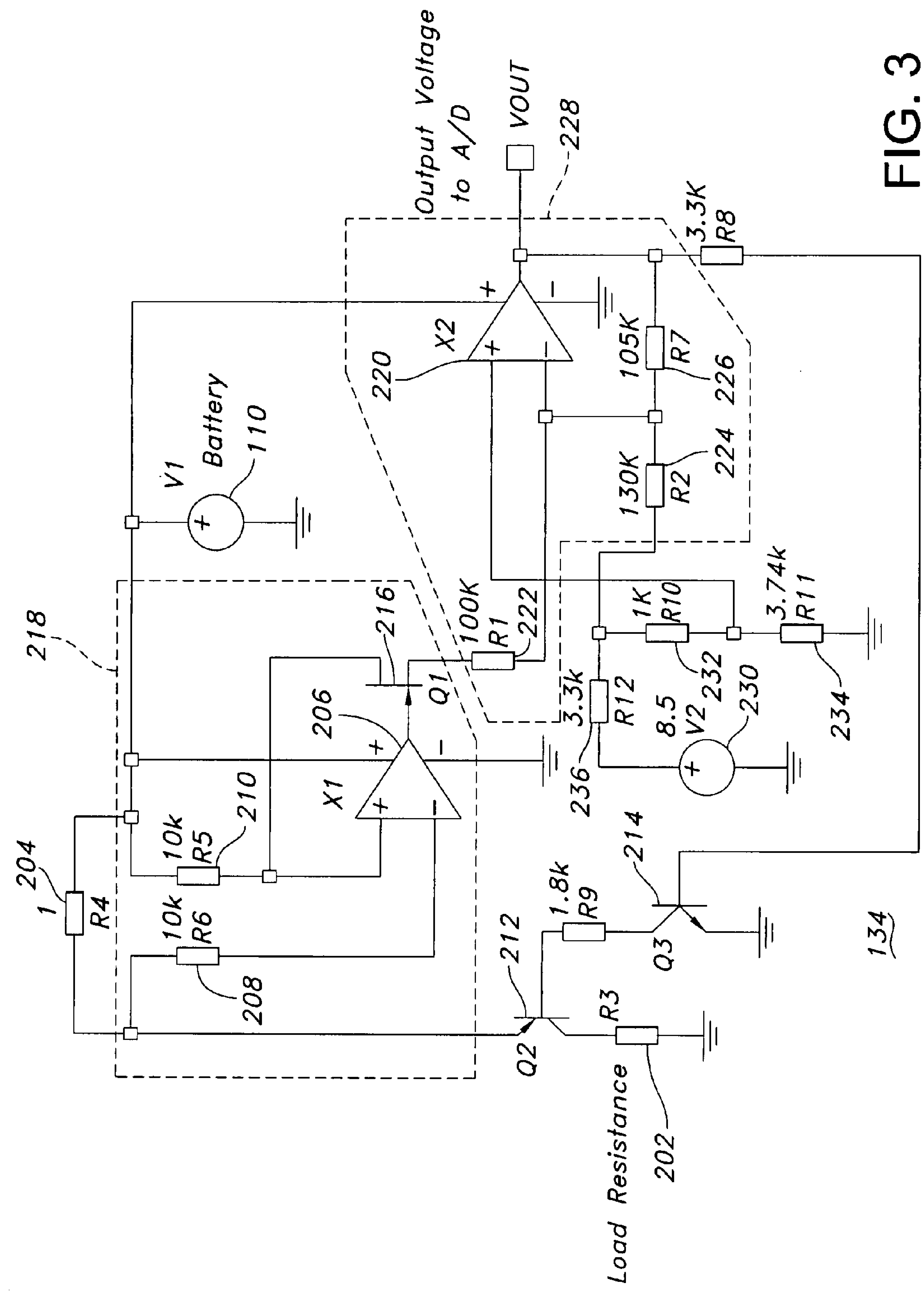

Output Voltage to A/D
VOUT
228
3.3K
R8
105K
R7
226
X2
220
130K
R2
224
V1
Battery
110
218
216
100K
R1
222
1K
R10
3.74k
R11
206
Q1
3.3k
R12
8.5
V2
232
230
234
236
X1
210
10k
R5
204
1
R4
10k
R6
208
212
1.8k
R9
214
Q3
134
Q2
R3
Load Resistance
202

FIG. 3

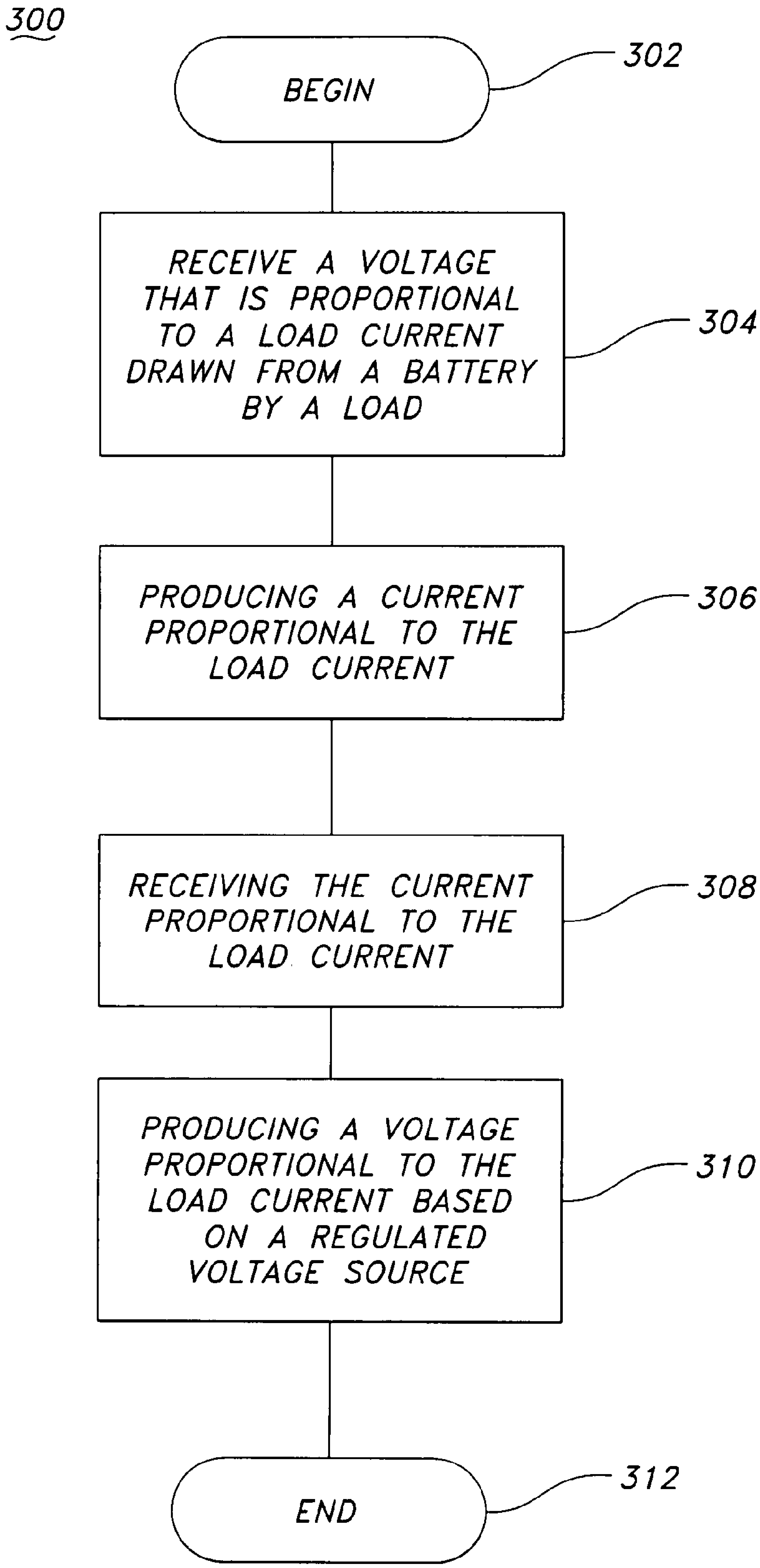

300
BEGIN
302
RECEIVE A VOLTAGE THAT IS PROPORTIONAL TO A LOAD CURRENT DRAWN FROM A BATTERY BY A LOAD
304
PRODUCING A CURRENT PROPORTIONAL TO THE LOAD CURRENT
306
RECEIVING THE CURRENT PROPORTIONAL TO THE LOAD CURRENT
308
PRODUCING A VOLTAGE PROPORTIONAL TO THE LOAD CURRENT BASED ON A REGULATED VOLTAGE SOURCE
310
END
312

FIG. 4

CURRENT SENSING SYSTEM AND METHOD

FIELD OF THE INVENTION

The present invention generally relates to automotive audio systems. In particular, the present invention relates to a current sensing circuit having a wide common mode voltage tolerance, measurement device protection and current limiting.

BACKGROUND OF THE INVENTION

In many electronic systems, it is desirable to be able to measure the current drawn by one or more components or subsystems. Current drawn is related to the overall energy consumption of the system. If the current drawn by all devices of interest is accurately sensed, an accurate computation of energy being consumed by the system may be performed. If current measurements are not accurate, the accuracy of the overall energy calculation is reduced. Most motorized vehicles (for example, cars, buses and the like) include electronic systems that are subject to adverse conditions that may impact the accuracy of current measurements because of the location of the electronic systems in or on the vehicle. A significant factor that may affect current measurement accuracy is that automotive batteries are typically subject to wide swings in output voltage. Battery voltage swings result from many factors, including loading and state of battery charge. Another factor that is likely to affect measurement accuracy is a wide variation in temperature at the location where current is being measured. For example, an automotive engine compartment is subject to wide temperature variation depending on such factors as operating conditions and seasonal temperature change.

In addition, it may be desirable to provide short circuit protection for a load while the current flow to the load is measured. Another complicating factor is the desire to obtain an accurate current measurement in a manner that utilizes as little battery voltage as possible. In systems in which it is desirable to provide a digital value corresponding current drawn by a load, still another factor complicating current measurement is the desirability of protecting an analog-to-digital converter adapted to produce the digital value from being damaged by an over-voltage condition. For these reasons, it is a challenging problem to obtain accurate current draw measurements for devices and electronic systems that are powered by a battery in a motor vehicle.

SUMMARY OF THE INVENTION

There is provided a current sense circuit. An exemplary current sense circuit comprises a voltage-to-current converter circuit that is adapted to receive a voltage that is proportional to a load current drawn from a battery by a load and to produce a current proportional to the load current, and a current-to-voltage converter circuit that is adapted to receive the current proportional to the load current and to produce a voltage proportional to the load current based on a regulated voltage source.

BRIEF DESCRIPTION OF THE DRAWINGS

The above-mentioned and other features and advantages of the present invention, and the manner of attaining them, will become apparent and be better understood by reference to the following description of one embodiment of the invention in conjunction with the accompanying drawings, wherein:

FIG. **1** is a block diagram of a motorized vehicle in accordance with an exemplary embodiment of the present invention;

FIG. **2** is a block diagram of an audio subsystem of the vehicle shown in FIG. **1** in accordance with an exemplary embodiment of the present invention;

FIG. **3** is a schematic diagram of a current sensing circuit in accordance with an exemplary embodiment of the present invention; and

FIG. **4** is a process flow diagram of a method in accordance with an exemplary embodiment of the present invention.

Corresponding reference characters indicate corresponding parts throughout the several views. The exemplifications set out herein illustrate a preferred embodiment of the invention, in one form, and such exemplifications are not to be construed as limiting in any manner the scope of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

This section is intended to introduce the reader to various aspects of art which may be related to various aspects of the present invention which are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present invention. Accordingly, it should be understood that these statements are to be read in this light, and not as admissions of prior art.

FIG. **1** is a block diagram of a motorized vehicle in accordance with an exemplary embodiment of the present invention. The motorized vehicle is generally represented by the reference number **10**. The exemplary motorized vehicle **10** comprises an engine **12**, a power train **14**, a plurality of electronic control systems **16** that may be adapted to control a number of vehicle systems (for example, the engine, the power train, a heating ventilation air conditioning (HVAC) system, to name a few examples), and a chassis **18**. The chassis **18** is adapted to support the engine **12**, which is adapted to drive the power train **14**. Also included in the exemplary motorized vehicle **10** is an entertainment system, which may provide audio/visual entertainment, computer networking capability or the like to occupants of the motorized vehicle **10**. The entertainment system **20** comprises an audio subsystem **22**, the operation of which is explained in greater detail below.

FIG. **2** is a block diagram of the audio subsystem **22** of the vehicle **10** shown in FIG. **1** in accordance with an exemplary embodiment of the present invention. The audio subsystem **22** comprises an audio processing module **102**. An active antenna **104** is adapted to receive a broadcast signal such as an AM/FM radio signal. Those of ordinary skill in the art will appreciate that the active antenna **104** may be adapted to receive other types of signals, such as satellite radio signals or the like. The broadcast signal received by the active antenna **104** is delivered via a coaxial cable **106** to the audio processing module **102** via an antenna connector **108**. As set forth below in greater detail, it may be desirable to measure a current flow being drawn by the active antenna **104**.

A battery **110**, such as a typical automotive battery, is adapted to deliver voltage to a main connector **112** of the audio processing module **102**. Specifically, the battery is adapted to deliver an input voltage to a battery voltage input **116** of the main connector **112**. The main connector **112** may include inputs and/or outputs for additional signals. For example, the main connector **112** may include an external I/O signal **114** and/or a network communications signal such as a LAN signal **118**.

The broadcast signal received by the active antenna **104** is delivered to a combiner **120**. The combiner **120** provides the signal to a primary AM/FM tuner **122**, an optional secondary tuner **124** and a phantom power coupler **126**. The phantom power coupler **126** is adapted to couple DC voltage from the battery **110** onto the coaxial cable **106** feeding the active antenna **104**, without compromising reception of radio signals on the coaxial cable **106**. Outputs from the primary AM/FM tuner **122** and the optional secondary tuner **124** are delivered to a digital IF processor **128** for processing. The digital IF processor **128** is powered by a power amplifier **130**, which receives power from battery voltage input **116** of the main connector **112**.

A main microprocessor **132** is adapted to control the overall operation of the audio processing module **102**. The battery voltage input **116** provides power to the main microprocessor **132**. The digital IF processor **128** delivers demodulated audio to the power amplifier **130**, which delivers amplified audio to the main connector **112**. Those of ordinary skill in the art will appreciate that control and status signals are exchanged between the digital IF processor **128** and the main microprocessor **132**. Moreover, the main microprocessor **132** does not directly receive audio signals from the digital IF processor **128**, but instead receives information in response to queries. That information may include information about the audio signals being processed. The amplified audio signal from the power amplifier **130** is used to provide an audio program for occupants of the vehicle **10** (FIG. **1**). As explained in detail below, the main microprocessor **132** is adapted to measure the current drawn by the active antenna **104** using a current sense and short circuit protection circuit **134**.

FIG. **3** is a schematic diagram of the current sense and short circuit protection circuit **134** (referred to hereafter as the current sense circuit **134**) in accordance with an exemplary embodiment of the present invention. The resistance values shown in FIG. **3** are exemplary in nature and not essential to the invention disclosed and claimed herein. Moreover, one of ordinary skill in the art would be able to identify appropriate component values for the current sense circuit **134** without undue experimentation given the benefit of the disclosure set forth herein.

The current sense circuit **134** is adapted to measure the current drawn by a load **202**, which may comprise a resistance presented by the active antenna **104** (FIG. **2**). In an exemplary embodiment of the present invention, the current sense circuit **134** is adapted to measure the flow of current in the presence of a significant and variable voltage, and to avoid over-ranging an analog-to-digital converter or other measurement display device. The main microprocessor **132** (FIG. **2**) may comprise an analog-to-digital converter to provide a digital representation of a value of the current being drawn by the load **202**.

The current sense **134** is powered by the battery **110** (FIG. **2**). Current drawn by the load **202** also passes through a current sense resistor **204**. The resistance of the current sense resistor **204** can be arbitrarily small to provide a minimal voltage drop between the battery **110** and the load **202**. The voltage drop across the current sense resistor **204** is applied differentially to an operational amplifier **206** via a first input resistor **208** and a second input resistor **210**. The current drawn by the load **202** also flows through a transistor **212**. The transistor **212** is held in saturation by base drive supplied by a transistor **214**, which is also normally saturated.

The operational amplifier **206**, the first input resistor **208** and the second input resistor **210** work in conjunction with a transistor **216**, to form a voltage-to-current converter circuit **218**, shown in dashed lines in FIG. **3**. The output current from the source of the transistor **216** is proportional to the voltage drop across the current sense resistor **204**. The voltage drop across the current sense resistor **204** is applied across the second input resistor **210**. Because the input terminals of the operational amplifier **206** are high impedance, the current that flows through the second input resistor **210** also flows through the transistor **216**.

The transistor **216** is desirably a Junction Field Effect Transistor (JFET) rather than a bipolar transistor because JFETs are voltage-biased. This means that the problem of variation in bias current present in a bipolar transistor is not present in a JFET. This characteristic results in improved temperature stability for the current sense circuit **134**. As an additional advantage, the use of a JFET also results in a relatively small gate current (leakage current not necessary to the operation of the JFET) compared to the base current of a bipolar transistor. Because the gate current of a typical JFET is very small, the gate current is subject to less variation that could otherwise occur during the relatively wide temperature variations encountered in the engine compartment of a motor vehicle.

The output of the voltage-to-current converter **218** is one of the inputs applied to a current-to-voltage converter circuit **228** (shown in dashed lines in FIG. **3**) that includes an operational amplifier **220**, a resistor **222**, a resistor **224** and a resistor **226**. Also provided to the current-to-voltage converter circuit **228** are bias voltages derived from a regulated voltage source **230**. The bias voltages are determined by the values of a resistor **232**, a resistor **234** and a resistor **236**. Those of ordinary skill in the art will appreciate that converting a small voltage drop across the current sense resistor **204** into a current proportional to a load current drawn from the battery **110** and the subsequent re-conversion of the current to a voltage value proportional to the load current using the regulated voltage source **230** has the effect of reducing variations in sensed current based on temperature fluctuations. This is true because the regulated voltage source **230** is typically less susceptible to temperature variation than is the battery **110**.

Those of ordinary skill in the art will appreciate that the circuitry around the operational amplifier **220** is adapted to provide a maximum output value when the current through the current sense resistor **204** is at a minimum. Moreover, the output voltage of the operational amplifier **220** falls as the current through the current sense resistor increases. The zero-current output voltage and the gain of the output of the operational amplifier **220** are adjusted by varying the component values of the circuit components of the current-to-voltage converter circuit **228** (the resistors **224**, **226**, **232**, **234** and **236**). The inverse-scaled output of the current-to-voltage converter circuit **228** prevents over-voltage damage to a circuit such as an analog-to-digital circuit that receives the output of the current-to-voltage converter circuit **228** because its output is at a predetermined maximum when the current being measured is zero, and falls to zero at some maximum current, determined by the choice of scaling components. A further increase in load current does not produce any further change in output.

FIG. **4** is a process flow diagram of a method in accordance with an exemplary embodiment of the present invention. The process is generally referred to by the reference number **300**. At block **302**, the process begins. A voltage that is proportional to a load current drawn from a battery by a load is received at block **304**. At block **306**, a current proportional to the load current is produced. The current proportional to the load current is received at block **308**. At block **310**, a voltage proportional to the load current based on a regulated voltage source is produced. The process ends at block **312**.

Those of ordinary skill in the art will appreciate that exemplary embodiments of the present invention do not require tightly matched precision components to eliminate the effect of the varying common-mode voltage and/or varying temperature. Additionally, embodiments of the present invention do not require separate, isolated power supplies and/or expensive isolation components such as transformers or optical isolators. Unlike known current sense and short circuit protection circuits, exemplary embodiments of the present invention do not require additional components, such as clamping diodes, to protect against over-voltages at their outputs. Known methods of current limiting usually require a series resistance in line with the load that can drop enough voltage to turn on a transistor, around 0.7 volts. In contrast, an exemplary embodiment of the present invention makes use of the output that is already there to supply the base drive for the current limiting transistor.

Exemplary embodiments of the present invention facilitate accurate current measurement over a wide range of operating conditions. For example, the current sense circuit **134** may be adapted to accurately sense current flow despite fluctuations in a range of operating temperatures at a measurement site from about −40 to +85 degrees Celsius and battery voltage swings ranging from about 9 to 16 volts.

While the invention may be susceptible to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and will be described in detail herein. However, it should be understood that the invention is not intended to be limited to the particular forms disclosed. Rather, the invention is to cover all modifications, equivalents and alternatives falling within the spirit and scope of the invention as defined by the following appended claims.

What is claimed is:

1. A current sense circuit (**134**), comprising:

a voltage-to-current converter circuit (**218**) that is adapted to receive a voltage that is proportional to a load current drawn from a battery (**110**) by a load (**202**) and to produce a current proportional to the load current; and

a current-to-voltage converter circuit (**228**) that is adapted to receive the current proportional to the load current and to produce a voltage proportional to the load current based on a regulated voltage source (**230**).

2. The current sense circuit (**134**) recited in claim **1**, wherein the voltage-to-current converter circuit (**218**) comprises a Junction Field Effect Transistor (JFET) transistor (**216**) that produces the current proportional to the load current drawn from the battery (**110**).

3. The current sense circuit (**134**) recited in claim **1**, comprising a current sense resistor (**204**) having a voltage drop that is applied differentially to the voltage-to-current converter circuit (**218**).

4. The current sense circuit (**134**) recited in claim **1**, comprising an analog-to-digital converter (**132**) that is adapted to produce a digital output corresponding to the voltage proportional to the load current.

5. The current sense circuit (**134**) recited in claim **1**, wherein the current-to-voltage converter circuit (**228**) is adapted to produce an output voltage that falls as the current proportional to the load current increases.

6. The current sense circuit (**134**) recited in claim **1**, wherein the load (**202**) comprises an active antenna (**104**).

7. The current sense circuit (**134**) recited in claim **1**, wherein the current sense circuit (**134**) comprises a portion of a vehicle audio subsystem (**22**).

8. The current sense circuit (**134**) recited in claim **1**, wherein the battery (**110**) comprises an automotive battery.

9. The current sense circuit (**134**) recited in claim **1**, wherein the voltage-to-current converter circuit (**218**) comprises a single Junction Field Effect Transistor (JFET) transistor (**216**) that solely produces the current proportional to the load current drawn from the battery (**110**).

10. A method (**300**) of sensing current drawn by a load (**202**), the method (**300**) comprising:

receiving (**304**) a voltage that is proportional to a load current drawn from a battery (**110**) by a load (**202**);

producing (**306**) a current proportional to the load current;

receiving (**308**) the current proportional to the load current; and

producing (**310**) a voltage proportional to the load current based on a regulated voltage source (**230**).

11. The method recited in claim **10**, wherein the current proportional to the load current is produced by a Junction Field Effect Transistor (JFET) (**216**).

12. The method recited in claim **10**, comprising differentially applying a voltage drop to produce the current proportional to the load current.

13. The method recited in claim **10**, comprising producing a digital output corresponding to the voltage proportional to the load current.

14. The method recited in claim **10**, comprising causing the voltage proportional to the load current to fall in response to a rise in the current proportional to the load current.

15. The method recited in claim **10**, wherein the load (**202**) comprises an active antenna (**104**).

16. The method recited in claim **10**, wherein the current proportional to the load current is produced solely by a single Junction Field Effect Transistor (JFET) (**216**).

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